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Migration Patterns and Spawning Site Selection by Virginia Lake Sockeye Salmon
and Final Conclusions for Fishery Management

Annual Report and Final Conclusions for Study FIS 01-179-3

[Where “01” is fiscal year study first funded, “179” is study identification number, and “3” is project year.]

The work discussed in this report culminates a three-year study but only addresses the final project year. The companion report FIS 01-179-1/2 summarizes the first two years of the study.

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Report Summary Page

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Abstract: Some populations of Pacific salmon travel great distances to spawn, and successful migration through lotic corridors is paramount to the perpetuation of a given stock. Virginia Lake sockeye salmon migrate 1.2 km up Mill Creek to reach upstream spawning grounds where they were believed to be primarily tributary spawners. In addition, recent escapement data suggest a dramatic population decline over the last 10 years. To better understand the biology and dynamics of this stock, 100 adult sockeye salmon were tagged with esophageal-implant radio transmitters across the breadth of their run from 22 July to 5 September 2003. Fish were tagged in Mill Creek and followed through their migration into Virginia Lake and to subsequent spawning areas. Seventy-eight of the tagged fish successfully migrated into Virginia Lake but took an average of 4.1 days to travel through Mill Creek. Fish entering the system after 9 August were only moderately successful at migrating into Virginia Lake. Of the fish tracked through the season, approximately 60% appeared to spawn in a localized portion of the northeast section of the lake and approximately 15% were divided between the lower reaches of Porterfield and Glacier Creeks.

Key Words: Mill Creek, *Oncorhynchus nerka*, radio telemetry, sockeye salmon, subsistence fishery

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INTRODUCTION

Sockeye salmon (*Oncorhynchus nerka*) are an important commercial and subsistence resource across most of their range. Their biology and population dynamics have been studied extensively (Foerster 1968, Burgner 1991, Varnavskaya 1994, Gustafson et. al. 1997), and a review by Halupka et. al. (1995) specifically depicts southeast Alaska stocks. Among a range of life history strategies exhibited by sockeye, the most common reproductive and developmental environment includes a lake system connected to saltwater by a stream or river. In addition, sockeye are also well known for their exceptional ability to home to their natal systems and often to the very area where they were spawned (Hasler and Scholz 1983, Burgner 1991, Varnavskaya et. al. 1994). Partly due to the lake rearing trait and strong homing tendencies, sockeye salmon have been popular subjects for artificial propagation and bioenhancement programs in Alaska to supplement commercial catches (Halupka et. al. 1995). However, the effects of supplemental propagation and stock mixing on the integrity and sustainability of unspoiled ecosystems and endemic stocks are not well understood.

Radio telemetry methods are an important and highly successful means of monitoring fish movements particularly when direct observation is limited due to water clarity and/or fish depth and where logistics and high costs prevent extensive field work (Winter 1983, 2000). It is a technique that is especially applicable for species like Pacific salmon that have extensive migrations to remote spawning areas (Eiler 1995). More recently, advances in radio telemetry technology have enabled researchers the ability to not only track tagged individuals, but also monitor activity levels as the fish moves about and encounters areas that require varying degrees of physical exertion (Hinch et. al. 1996, Hinch and Rand 1998, Hinch and Bratty 2000, Hinch et. al. 2002, Standen et. al. 2002). However, despite the many advances and increasingly simplified operating platforms, it is extremely important to carefully consider the study design and application of the technology prior to implementing a telemetry study to acquire the desired information (Winter 2000).

Relatively little is known about the behavior of the Virginia Lake sockeye population in southeast Alaska despite years of intensive management (Cady and Reed 2003). Recent observations suggest that the stock is declining, but concrete evidence as to why this appears to be the case is lacking. Although the possibilities are wide ranging, most explanations fall into two main categories. The first category concerns the overall productivity of Virginia Lake. Despite extensive fertilization programs to boost productivity, smolt production still appears to be declining. The second category concentrates on the adult sockeye. Virginia Lake was planted with a non-endemic stock of sockeye fry for seven years (1989-1995) with adult return expectations in excess of 20,000 (Cady and Reed 2003). Unfortunately, no accurate records exist that assess the escapements from these progeny, but the present escapement is probably less than 3,000 (pers. obs.). The available data do little to provide direct evidence to explain the failures in this system. To gain greater insight on the problems surrounding sockeye salmon production in Virginia Lake, this study focused on obtaining specific information on the migration abilities and spawning site selection of adult sockeye in the system and used radio telemetry technology to obtain the data.

OBJECTIVES

The 2003 work culminates a three-year Virginia Lake stock assessment but imparts a substantial change to the original project objectives (*see* Cady and Reed 2003). Our efforts focused exclusively on tracking radio-tagged adult sockeye salmon through Mill Creek and Virginia Lake to determine the ultimate fate of each individual fish. The goals of the 2003 field season were to:

1. Describe the proportion of radio-tagged sockeye salmon that migrate through Mill Creek into Virginia Lake, and;
2. Describe the proportions of radio-tagged sockeye salmon that spawn in the inlet tributaries and/or within the lake (i.e., determine if any previously unidentified spawning areas exist in the system).

METHODS

Study Site

The Virginia Lake system is on the mainland approximately 8 km east of Wrangell, Alaska (Figure 1). It lies in a steep mountain cirque basin ranging in elevation from sea level to over 1000 m. The entire watershed encompasses approximately 10,495 ha. Spruce-hemlock forest, interspersed with pockets of muskeg, comprises the majority of the sub-alpine terrestrial environment. Mill Creek, Virginia Lake, the mid-lower portion Glacier Creek, and the mid-lower reaches of Porterfield Creek provide spawning and rearing habitat to anadromous and resident fish. Sockeye salmon are the most abundant salmon species in the Virginia Lake system. Pink (*O. gorbuscha*), chum (*O. keta*), coho (*O. kisutch*), and chinook (*O. tshawytscha*) salmon have all been observed in the system (unpublished data). The lake also supports populations of anadromous and resident Dolly Varden char (*Salvelinus malma*) and cutthroat trout (*O. clarki*), and resident populations of stickleback (*Gasterosteus aculeatus*) and sculpin (*Cottus* sp.).

Virginia Lake is 257 ha in size and has a perimeter of 9.9 km. The lake has a general east-west profile and is organically stained. Glacier Creek and Porterfield Creek are the two main tributaries to Virginia Lake; both are mostly clearwater systems with some staining in the lower reaches. Both creeks derive most of their annual flow volume from precipitation, but small permanent ice fields in the headwaters contribute, as well. Porterfield Creek drains the main valley and possesses four reaches deemed acceptable for anadromous fish spawning: 1) the South Arm (2.6 km); 2) the North Arm (2.2 km); 3) a section that connects the North and South Arms (0.5 km - flowing from south to north); and 4) upper Porterfield Creek (1.1 km). Glacier

Creek drains an icecap and glacier basin, but is largely a clearwater system with some organic staining in the lowermost reach. It contains four areas deemed acceptable for anadromous fish spawning. Moving progressively upstream from the lake, these include: 1) a low-gradient 0.8 kilometer floodplain reach; 2) a moderate gradient bedrock and boulder riffle reach approximately 2.0 kilometers in length; 3) a low gradient highly braided floodplain reach with a total channel length of 8.3 km; and 4) a moderate gradient cobble and boulder riffle with a length of 0.6 km.

Mill Creek exits the west end of the lake and flows approximately 1.2 km to saltwater. Fish entering Mill Creek encounter four falls of varying size and complexity prior to entering Virginia Lake. This short stream possesses limited spawning habitat due to its moderate-deep channel incision and bedrock containment, abundance of bedrock and boulder substrate, and moderate gradient. However, there are two sites where spawning is suspected: 1) the lake outlet at the juncture where Virginia Lake becomes Mill Creek; and 2) the tailout of the Flume Pool, approximately 0.2 km upstream from saltwater.

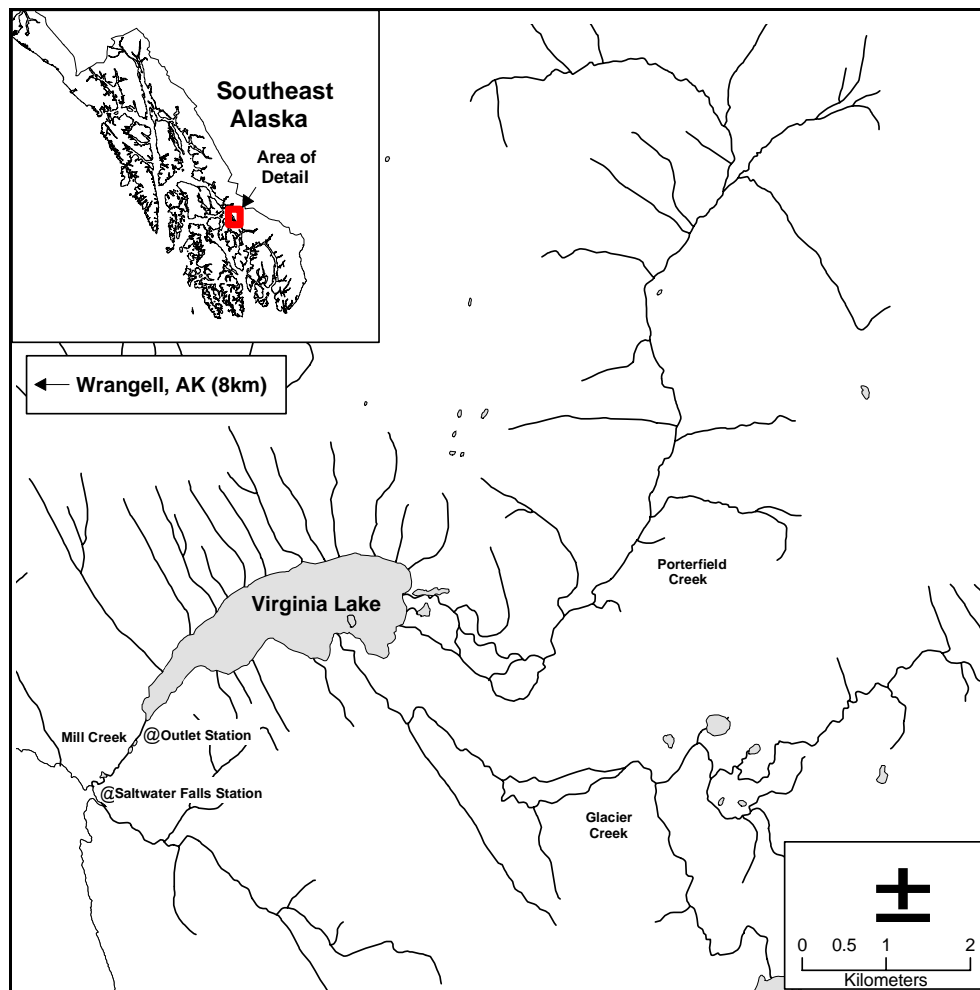


Figure 1. Virginia Lake and tributaries.

Telemetry Study Design and Data Analysis

Radio telemetry has been widely used to study the movement and spawning behaviors of sockeye salmon, and standard methodologies are now commonly employed in most studies. The methods used in this study closely resembled the work of Eiler et. al. (1992), Burger et. al. (1995), Schubert and Scarborough (1996), and Young et. al. (2002).

Capture and Handling

We captured upstream migrating sockeye salmon in a top-of-fishpass trap located at the lowermost (saltwater) waterfall (Cady and Reed 2003). Trapping began on 14 July and ended on 5 September. The trap was inspected and fish were processed daily from 0800-1200. Fish entering the trap after this time were left until the next day to facilitate physiological stabilization from the saltwater to freshwater transition.

Individuals for tagging were selected from the daily captures to acquire a sample that demonstrated the breadth of characteristics inherit to the run. We wanted a sample of tagged fish that was evenly distributed among sexes, proportionate to the dominant size classes greater than 450 mm mid-eye to fork length (tag size limited application to larger fish), and distributed proportionate to the run strength at time. Generally, the first 1-10 fish captured by dipnetting in the trap were radio-tagged on a given day.

After being removed from the trap, fish were placed in a tagging cradle submerged in a trough containing a 30 mg/L clove oil and fresh water solution (6 ml of 10% clove oil solution with 20 L of fresh water). Fish were monitored until gill ventilation slowed and resistance to handling was reduced - approximately 1-2 minutes. Woody et. al. (2002) describes the effectiveness and utility of administering a clove oil anesthetic to sockeye salmon in radio-tagging studies. We experienced similar reactions from sockeye as those anesthetized with a 20 mg/L clove oil solution in the aforementioned study, but we were trying to minimize the recovery time and, thus, overall handling time. Fish were sexed, measured to the nearest mm (mid-eye to fork), scale sampled, and tagged with a 168 MHz pulse coded transmitter supplied by Advanced Telemetry Systems (model #F1840). Transmitters were 51 cm long x 17 cm diameter and coated with a biologically inert electrical resin with a 30.5 cm stainless steel, nylon coated whip antenna. The radio transmitter was inserted through the mouth and placed in the stomach with a 15 cm section of semi-rigid plastic tubing. Fish were then moved to a quiet pool upstream of the trap and manually resuscitated until the fish was able to swim off on its own volition. The whole process generally took less than five minutes to perform. A portion of the surplus captures from each day were anesthetized and sampled for age (scales), sex, and length then released in the same manner as the tagged fish. All remaining captures were passed upstream of the trap.

Streamflow. A relative discharge assessment was made on each tagging and/or tracking day during the migration period. Relative discharge was assessed by visually observing the amount

of water passing through a flow control weir just above the fishpass trap. The weir's control notch where water height was visually assessed measured approximately 1.0 m high by 0.7 m wide. The weir was originally constructed to provide water deflection away from the fishpass to allow easier fish handling at the trap, and made an ideal relative discharge assessment location because a proportion of the overall flow was always passing through the structure. Four flow stages were designated based on water height at the weir notch. "Low flows" were any water levels less than 0.25 m the height of the notch. "Normal flows" were gauged at water heights between 0.25 and 0.75 m. "High flows" demonstrated water heights of 0.75 to the top of the weir notch. "Extreme high flows" overtopped the weir notch and fishpass.

Tracking

Telemetry equipment consisted of two stationary receiver and datalogger units and one mobile receiver unit. All equipment was supplied and manufactured by Advanced Telemetry Systems, Inc. Two model R2100 receivers paired with Data Collection Computers (DCC's; i.e., dataloggers) were used at stations located at the lake outlet and just upstream of the lowermost waterfall (Figure 1). Each station was equipped with a four-element Yagi receiving antenna and powered by two deep cycle marine batteries that were replaced every 2-3 weeks. The dataloggers were programmed to record detections on a continuous basis. Crews tracked fish on foot along Mill, Glacier, and Porterfield Creeks and by boat on Virginia Lake with a R4100 receiver equipped with a three-element Yagi antenna.

Fish locations were determined within 1-5 m of actual positions during foot surveys on Mill Creek and within 2-15 m of actual positions during boat surveys on Virginia Lake. Tagged fish were tracked and visually observed during foot surveys on Glacier and Porterfield Creeks. We plotted locations for fish tracked in the system during all surveys on aerial photographs or simple topographic maps.

Spawning Criteria

Except for tributary spawners, determination of spawning locations and times for tagged fish remaining in the lake was relatively subjective. We reduced subjectivity in our determinations by assigning a presumed spawning site to fish tracked at the same area on multiple (two or more) occasions and if untagged fish were observed at the same location. In addition, we used a portable sonar (fishfinder) during lake surveys to assist in localizing individual or groups of fish. Because of Virginia Lake's small size and apparent lack of suitable spawning sites, it was assumed that lake spawning fish would limit spawning site selection to only a few key areas, thus enabling the crew to track them efficiently and consistently. Spawning time assignments were based on observations of tributary fish condition/status and fish found at a presumed lake spawning area.

Tag Retention

Seven additional sockeye were captured with an anchored gillnet (10.2 cm mesh) at the Flume Pool, approximately 200 m upstream of the trap site, to conduct a tag retention test. Fish were removed as quickly as possible to reduce stress and placed into a large (1.8 m x 1.5 m x 1.5 m) submersible cage that was secured to the stream bank. The cage frame was made of welded aluminum tubing (six individual pieces bolted together) and enclosed with a semi-rigid plastic, 2.5 cm meshing. Fish were left undisturbed for 48 hours. On the third day after capture, the seven fish were tagged with dummy transmitters of the same proportions and material type as the live tags. Dummy tags were implanted in the same manner as the study fish. Tag disposition was confirmed by the observation of an antenna protruding from each fish's mouth. Fish were monitored every 24-48 hours. Due to holding constraints, no controls were used in this evaluation.

Data Analysis

Age and length compositions of tagged fish were compared with untagged fish to test for sampling bias in this study. Chi-square tests of independence and two sample Kolmogorov-Smirnov (K-S) tests were used to make these determinations (Daniel 1990). Male and female lengths were compared with *t*-tests and ages were compared with a chi-square test for independence to examine for differences between sexes of the tagged fish population. A travel time in days was calculated for fish that were successfully tracked into Virginia Lake. Travel time trends were evaluated with simple linear regression and one-way analysis of variance procedures (Zar 1984)

A fate or final outcome was assigned to each tagged fish to examine the migration success and spawning location objectives (Table 1). Because of the scope of this study, fish fates are presented as simple proportions and no statistical models were applied to the data. In other words, the discussion of results was mostly inferential but based on the calculated proportions.

All fish successfully accepting and retaining a radio transmitter for at least two hours after tagging (n_T) were considered eligible lake migrants and spawners. The proportion of tagged fish that migrated into Virginia Lake (P_V) was calculated from the ratio of the fish passing the upper data logging station (n_I) to the total number of tagged fish minus any fish described as a Failure U (F_U), or:

$$P_V = n_I / (n_T - F_U)$$

where:

$$n_I = n_T - (F_1 + F_2).$$

Table 1. Final disposition (i.e., “fate”) designation and associated description applied to the 100 radio-tagged sockeye salmon.

Fate	Description
Lake Migrant	A fish that successfully migrated into Virginia Lake.
Spawner (Sp)	A fish that entered Virginia Lake and was subsequently observed at a spawning location or detected at a presumed spawning location ¹ .
Failure 1 (F ₁) – Saltwater	A fish that exited the system and did not re-enter Mill Creek and never entered Virginia Lake.
Failure 2 (F ₂) – Mill Creek	A fish that remained in Mill Creek through the duration of the study and eventually died while in the stream.
Failure 3 (F ₃) – Virginia Lake	A fish that entered Virginia Lake but was not detected during subsequent surveys nor at any spawning location, or was found or determined a mortality.
Failure U (F _U) - Unknown	A fish that was never recorded at any data logger or during a survey after tagging (i.e., tag failure, animal loss).

¹ Spawning locations in Virginia Lake could not be visually verified, but we presumed spawning on 1) multiple detections of individual fish at the same location and 2) large concentrations of tagged fish in a particular location across surveys.

Because Virginia Lake is 1) only 1.2 km from saltwater, 2) the lowermost waterfall is circumvented with a fishpass structure, and 3) Mill Creek has minimal fishing pressure (bear or human), a 90% migration success rate seemed a reasonable threshold to evaluate passage problems in the system. Less than a 90% success rate would signal the likelihood of significant migration obstacles existing in Mill Creek.

Spawning locations and relative spawning use for each area within Virginia Lake and its inlet tributaries was determined from the number of successful lake migrants (n_1) less Failure 3 (F₃). An area was considered a possible spawning site if: 1) a tagged fish was observed on or near a redd area; 2) a tag or spawned-out, tagged carcass was found on or near a redd area; or 3) a tagged fish remains in a particular area over multiple surveys and upon identifying at least 5 other tagged fish found to be occupying the same area. The proportion of fish classified as successful spawners (P_{sp}) was calculated as:

$$P_{sp} = n_2/n_1$$

where:

$$n_2 = n_1 - F_3.$$

Proportions of fish spawning in each location (P_a) were calculated by the following formula:

$$P_a = n_a/n_2$$

where n_a is the number of radio-tagged fish observed at a specific spawning location summed across all surveys and a is a specific area (e.g., a section of shoreline, a tributary or section of a tributary).

RESULTS

Tagged Fish

Radio-tagging of adult sockeye salmon at Mill Creek commenced on 22 July and ended on 5 September. One hundred fish, evenly divided between males and females, received an esophageal-implant transmitter (Appendix A). Lengths of tagged fish ranged from 490-640 mm (Figure 2). Peak numbers of fish were released in early August, which appeared to coincide with the peak migration period. No tag loss or failure was experienced during the first component of the study, and tag retention was 100% for the seven individuals tagged with dummy transmitters. However, these individuals were only monitored for six days until they died in the holding pen. Our tag retention success was similar to that observed by Ramstad and Woody (2003). Our test fish were from the latter part of the run and were possibly over-stressed by the gill net capture, which may have contributed to the early mortality.

Tagged sockeye tended to be somewhat larger than the untagged fish sampled at the trap (Figure 2). The length distribution of radio-tagged fish differed significantly from that of untagged fish (K-S test, $D_{\max} = 0.40$, $P < 0.001$). Males showed a broader size distribution than females, and smaller males were not represented in the tagged fish group. Tagged males were significantly longer even when jacks (males < 450 mm) were removed from the analysis (K-S test, $D_{\max} = 0.33$, $P < 0.001$). Smaller females were also underrepresented in the tagged fish group. Within the tagged fish group, males were significantly longer than females (t -test, $t = 3.68$, $P < 0.001$).

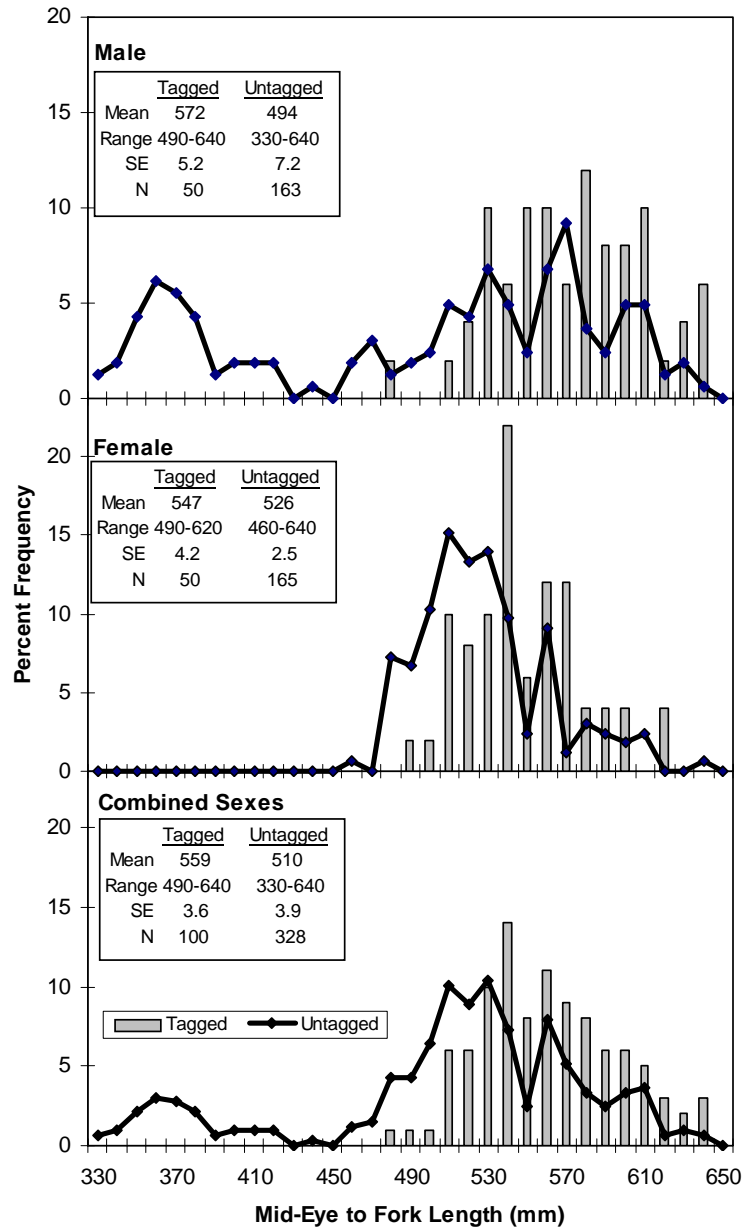


Figure 2. Numbers and lengths (mid-eye to fork of tail) of radio-tagged and untagged adult sockeye salmon from Mill Creek, Alaska, 2003.

The predominant age structure of the sockeye salmon sampled in 2003 consisted of fish that had spent either one or two years in freshwater and two years at sea (age 1.2 or 2.2; Figure 3); slightly over 60% of sampled fish were from these age classes. However, tagged fish were significantly older than untagged fish because males and females of age-1.3 and 2.2 were over-represented in the tagged fish group ($\chi^2 = 38.8$, $df = 8$, $P < 0.01$). Tagged fish were underrepresented in the age-1.2 group, 20% versus 34% in the untagged group. Age-1.3 fish composed 26% of the tagged fish but only 8% of the untagged sockeye salmon sampled from the

trap. In addition, age-2.2 fish composed 35% of the tagged fish and 29% of the untagged fish, which was a more comparable composition. There was essentially no difference in the age structure of tagged male and female fish ($\chi^2 = 3.14$, $df = 4$, $P > 0.10$).

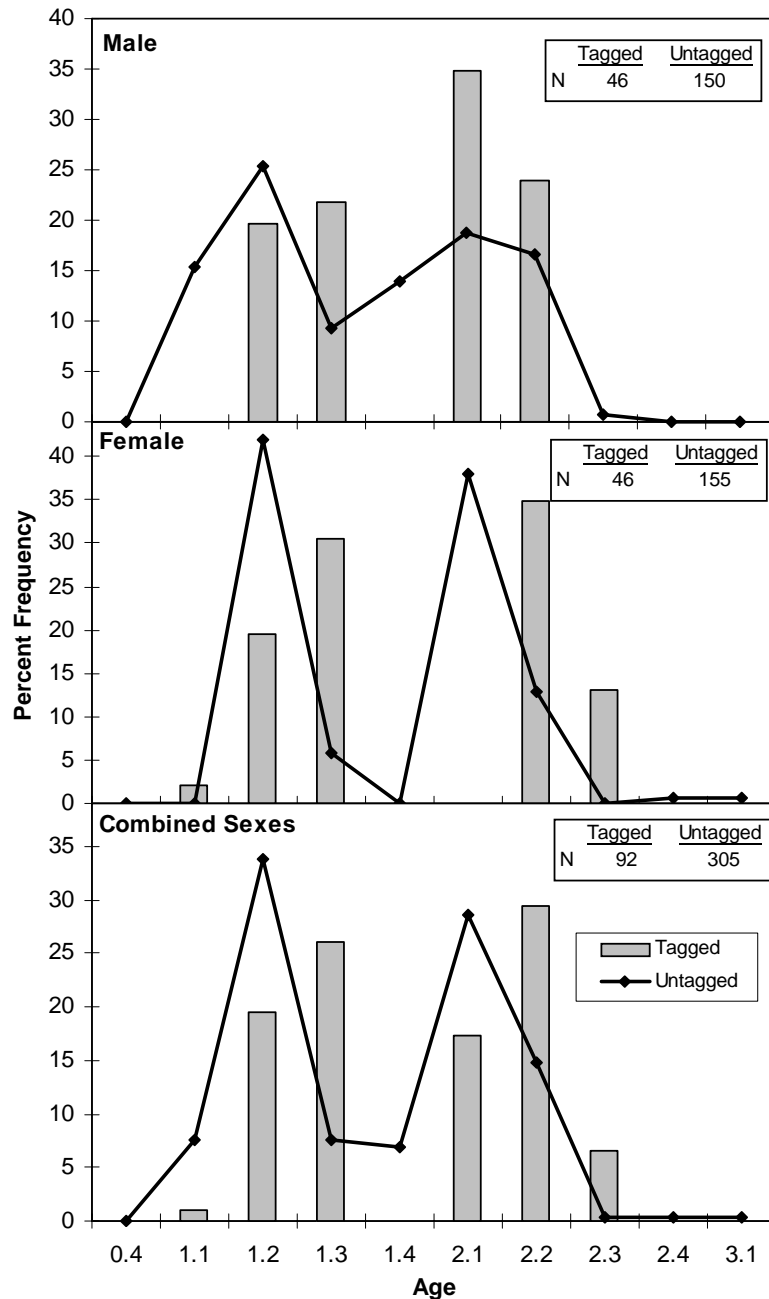


Figure 3. Numbers and ages (freshwater and marine life stages) of radio-tagged and untagged adult sockeye salmon from Mill Creek, Alaska, 2003. (Note: Aging for some tagged and sampled fish was incomplete.)

Upstream Migration and Spawning Distribution

Upstream Migration

All 100 radio transmitters were successfully deployed with no apparent anomalous behavior observed in either the fish or transponder performance within two hours of tagging. All fish were successfully tracked in Mill Creek at least once during their migration to Virginia Lake unless the fish moved into Virginia Lake or returned to saltwater between tagging and subsequent surveys. In addition, all tagged fish that entered Virginia Lake were successfully detected by the upstream data logging station. Most fish that returned to saltwater over the lowermost waterfall were detected by the downstream data logging station; those that were not detected ($n = 2$) were presumably swept away by flow velocities that exceeded the data logger's scan cycle-rate.

The close proximity of the Virginia Lake system to Wrangell enabled the field crew to make almost daily visits during the length of the run and at least weekly visits through the remainder of the season, weather permitting. As a result, a fairly precise migration scheme was determined for each individual tagged fish as it migrated through Mill Creek and into Virginia Lake. Radio-tagged adult sockeye salmon took, on average, 4.1 days (range 0.5-10.7) to migrate 1.2 km up Mill Creek from the trap at saltwater to the lake outlet. This translates to a travel time of 0.3 km/day. There was no apparent relationship between fish size and time to arrive at Virginia Lake (Figure 4; Regression $F_{(1,76)} = 0.17$, $r^2 < 0.01$, $P > 0.10$). However, the relationship between tag date and time to reach Virginia Lake was marginally significant (Figure 5; $F_{(1,76)} = 3.80$, $r^2 < 0.05$, $0.05 < P < 0.10$). This relationship becomes more obvious when tagged fish are grouped by statistical week (Figure 6). The most interesting feature of this pattern is the steady decline in the migration time from the first tagging period through the majority of the run. Fish tagged near the end of the run took the longest amount of time to reach the lake, and, in fact, had the lowest success rate (see next section). Flow regimes (relative) remained at mostly normal or low levels through the majority of the migration period. The first extreme high water event occurred on 30 August. As a result, and because discharge was not directly measured, migration times were not comparable to the range of flows the fish experienced over the course of the run.

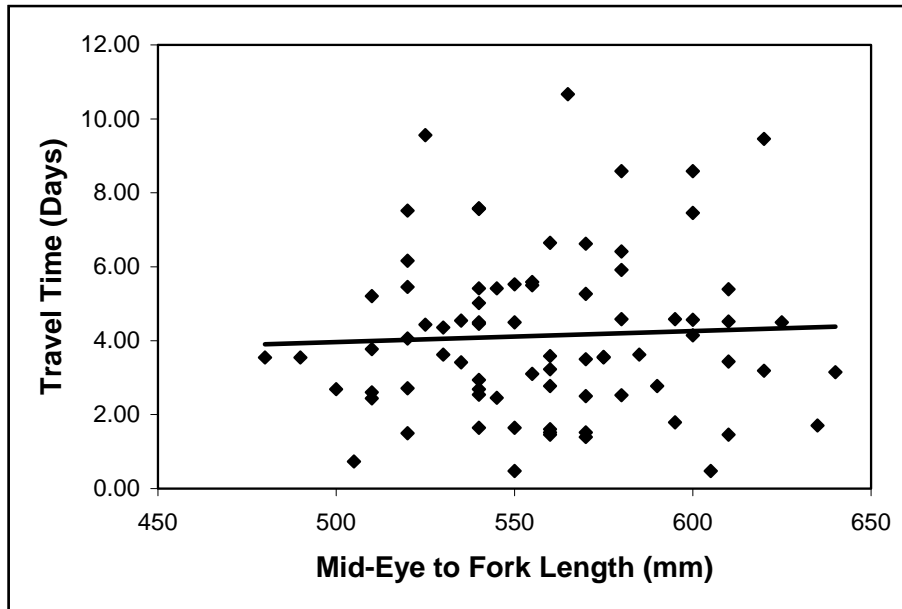


Figure 4. The relationship between fish size and the amount of time it took to reach Virginia Lake after tagging (n = 78).

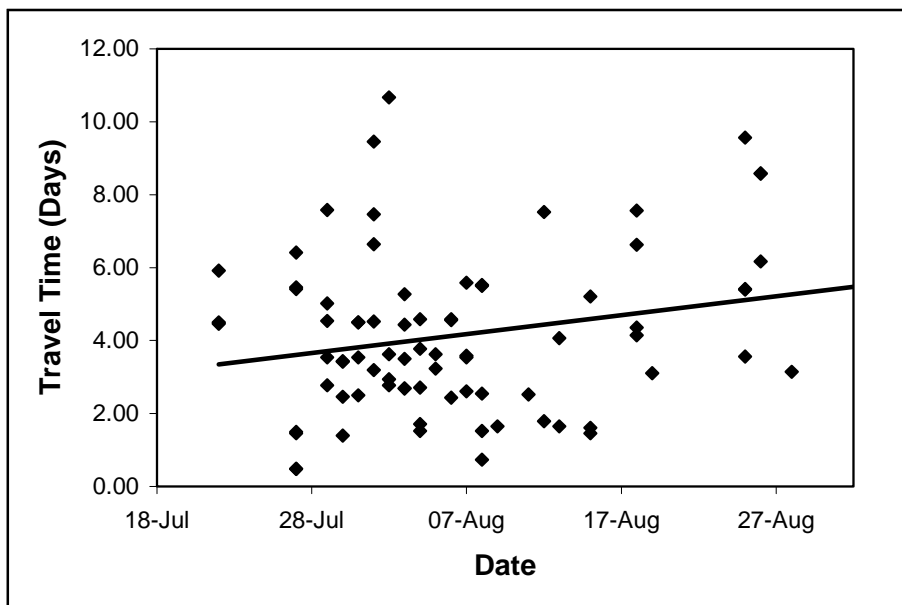


Figure 5. The relationship between tag date and the amount of time it took to reach Virginia Lake after tagging (n = 78).

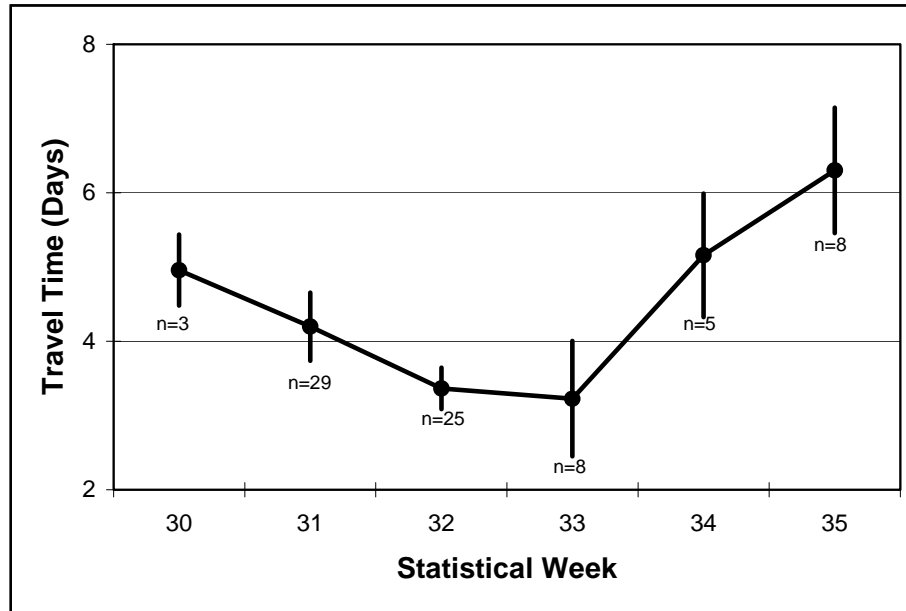


Figure 6. The relationship between tag week and the amount of time it took to reach Virginia Lake after tagging ($n = 78$; mean \pm SE).

Migration Success and Final Disposition of Tagged Fish

Migration Success. Roughly three-quarters ($P_v = 0.78$) of the 100 tagged sockeye salmon successfully negotiated Mill Creek and entered Virginia Lake over the course of this study (Table 2). The largest proportion of migration failures resulted in the fish returning to saltwater (18%) for unknown reasons, and no fish that returned to saltwater was recaptured in the trap or re-detected migrating past the downstream data logging station on days the trap was left open nor after the trap was removed for the season. Only four fish apparently died and remained in Mill Creek over the course of the study, and one of these tags was recovered from a carcass. Of the fish that never migrated to Virginia Lake, 41% were male and 59% were female. Most migration failures occurred with fish tagged between 9 August and 5 September. Thirty-eight fish were tagged in this period, and 18 of these fish failed to migrate to Virginia Lake. Figure 7 illustrates the overall migration success rate of the 100 tagged sockeye over time.

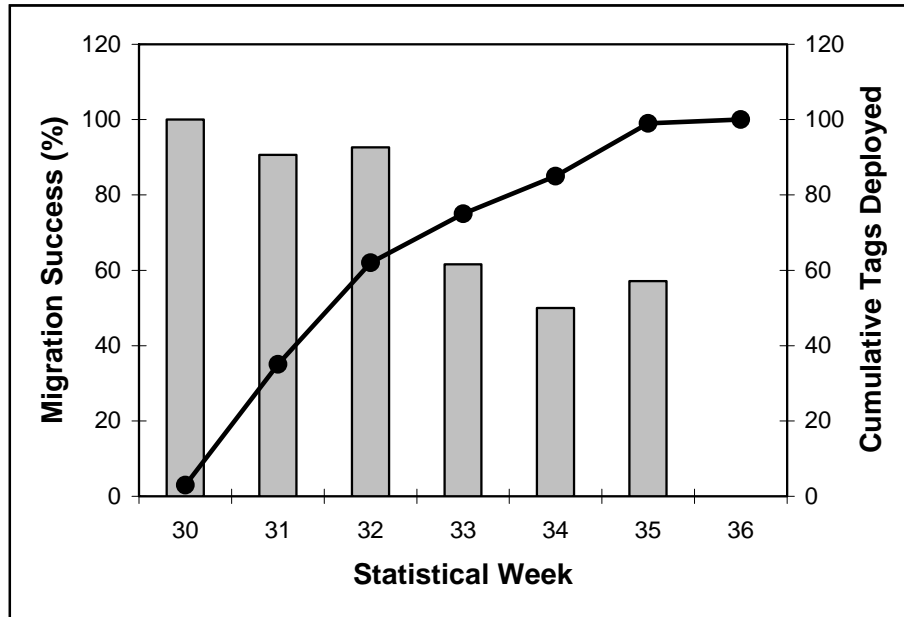


Figure 7. The relationship between Virginia Lake migration success rate (bars) and time of tagging by statistical week. Each bar corresponds only to the fish tagged by the end of the given week. The first bar represents a 100% lake migration success rate for the three fish tagged (line) by the end of week 30. Sixty-two tags were deployed by the end of statistical week 32, which corresponds to 9 August.

Since there are no other large lake systems near Virginia Lake, the field crew restricted the tracking area to the Virginia Lake basin. As a result, this study could not determine how many, if any, of the tagged fish that returned to saltwater strayed to other systems. However, five tags were recovered from the 18 that passed back to saltwater, and of these five, three were recovered from decomposing carcasses. Multiple tag recoveries in the Mill Creek estuary and the lack of other nearby sockeye systems suggest that most, if not all, saltwater returns resulted in mortalities, and that straying did not occur.

Lake Outcomes. Of the 78 fish that migrated into Virginia Lake, only 63 ($P_{sp} = 0.81$) were believed to be successful spawners (Table 2). Of the remaining 15 fish that were detected entering Virginia Lake, eight fish remained undetected after they passed the upstream data logging station; five fish subsequently exited the lake and were detected returning to saltwater past the downstream data logging station; and two fish were suspected lake mortalities. Roughly translated, the entire Mill Creek/Virginia Lake sockeye salmon run could have less than a 60% spawning success rate, and could be much less considering 26% of what were believed to be successful spawners were not verified as such.

Table 2. Disposition of 100 adult sockeye salmon radio-tagged and tracked in the Virginia Lake drainage, Alaska, 2003.

Category	Number (%) ^a of Fish
Number tagged (n_T)	100
Number migrating into Virginia Lake (n_L , P_V)	78 (78)
Number not migrating into Virginia Lake	22(22)
<u>Failure sub-categories (Initial)</u>	
Returned to seawater (F_1)	18(82)
Stream mortality (F_2)	4(18)
<u>Lake sub-categories</u>	
Spawner ^a (n_2 ; P_{Sp})	63(81)
Subsequent exit (F_3)	5(6)
Undetected (F_3)	8(10)
Mortality (F_3)	2(3)
<u>Spawning Distribution^b</u>	
Lake	38(60)
Tributaries	9(14)
Unknown ^c	16(26)

^aBased on total number for that sub-category

^bBased on direct observations and multiple same locality detections

^cOnly detected once after lake entry and not in primary spawning area

Spawning Distribution

The sockeye tagged in this study appeared to use three spawning areas in the Virginia Lake system (Figure 8). Exact spawning locations were determined for 47 of the 63 fish that were believed to be successful spawners (Table 2). The three areas included: 1) a section of the northwest shoreline on Virginia Lake ($n_L = 38$), 2) a short section of lower Glacier Creek ($n_G = 4$), and 3) a section of Porterfield Creek that started near the mouth of the north arm extended through the lower connector arm and ended just upstream of the connector channel-south arm split ($n_P = 5$). It should be noted that connector channel spawning habitat was only present in the immediate areas of the junction points.

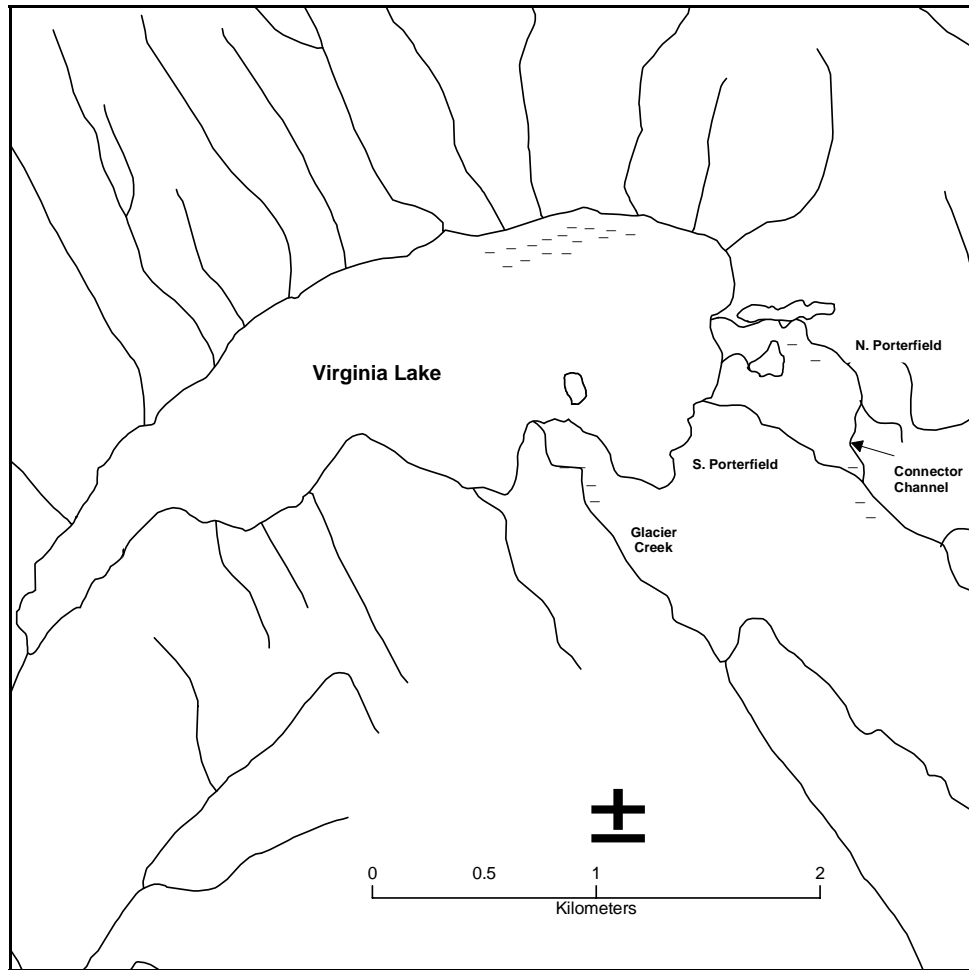


Figure 8. Locations and relative abundances (indicated by ,) of Virginia Lake sockeye spawning concentrations. Symbol positions are generalized to illustrate area-wide spawning locations and are not precise spawning locations.

The lake shoreline spawning area extended from roughly mid-lake to a point approximately 100 m from the recreation cabin at the most northeasterly corner of the lake (Figure 8). There was nothing visibly exceptional about this lake section, and the characteristics were, in fact, typified in other parts of the lake. The shoreline substrate was a highly mixed alluvial composite, but the visible submerged portions consisted mainly of sand and silt substrates. The transition from the lake margin to approximately 20 m offshore was roughly 45°. Large targets were marked at depths ranging from 2-15 m with the portable sounder, suggesting the presence of staging salmon. Tagged fish were encountered at this location during each lake survey, and 38 tags were encountered at least twice suggesting these fish remained in the area and used it for spawning (Table 2). Dying fish and spawned-out carcasses were either observed or collected and inspected during the last October surveys. However, no tags were recovered from this area. Peak lake spawning likely occurred between mid-September through mid-October.

Four tagged fish were tracked and observed in Glacier Creek during a survey on 1 October. These four fish were either paired or holding over redd areas. Other spawners and spawned-out carcasses were found in the same area. All of the observed fish were within a slightly braided section of stream that contains less than 350 m of wetted channel (Figure 8). It is the same stretch of Glacier Creek where the vast majority of spawning activity has been observed in years past. This section is characterized by a transition from a flood plain to a large contained stream channel (USFS 1992).

A total of five tags were tracked in Porterfield Creek during the 1 October survey. Three tags were tracked to spawning fish that were observed, one tag was found next to a decaying carcass, and one tag was tracked to, but not recovered from, an undercut streambank. The latter two tags were found in the vicinity of other spawning fish so it is likely that these tags were from fish that had already spawned. These findings suggest a total of five tagged fish spawned in Porterfield Creek. These fish and tags were observed from the north arm through the connector channel to the south arm, which is a stream section more than five times longer than the spawning area in Glacier Creek (Figure 8). Spawning fish have been observed in these same reaches in past years' surveys. This section of Porterfield Creek contains the majority of the flow during normal and low-flow periods. It is characterized by flood plain channel geomorphology and extends for roughly 1200 m (USFS 1992). However, the bulk of the connector section is largely unsuitable for spawning. Peak spawning in both steam systems appeared to occur in late September, and was probably slightly earlier than the peak lake spawning period.

There was no apparent relationship between freshwater entry time and spawning site selection for the tagged fish tracked in this study (Table 3). Individuals entering the system from the beginning to the end of the run chose to remain in the lake through the end of October – the presumed spawning period end. Though a small sample size, individuals choosing one of the two tributaries randomly entered freshwater through the peak of the run, but not during the latter part of the run. It is impossible to ascertain whether tributary spawners are at all distinct from lake spawners. There was also no apparent site selectivity among the sexes as five of the nine tributary fish were male and four were female. The tributary spawning males tended to enter the system slightly earlier than the females, but this is not uncommon among Pacific salmon. Interestingly, a higher proportion of jacks were observed in Porterfield Creek than in Glacier Creek during 2003 surveys.

Table 3. Spawning site selection and freshwater entry (tagging) time for Virginia Lake sockeye salmon.

Spawning Site	Freshwater Entry Dates
Virginia Lake ($n_L = 38$)	22 July – 26 August
Glacier Creek ($n_G = 4$)	29 July – 2 August
Porterfield Creek ($n_P = 5$)	29 July – 5 August

DISCUSSION

A fish passage structure was constructed around the lowest downstream waterfall on Mill Creek at the onset of enhancement efforts at Virginia Lake. Managers believed that circumvention of this waterfall would allow sockeye salmon easy passage through Mill Creek to spawning grounds in Virginia Lake and its tributaries, but migration dynamics were never assessed after the construction and subsequent modification of the fish passage structure nor was a survey ever completed to identify all primary spawning areas in the system (Cady and Reed 2003). The present study evaluated sockeye migration behavior through Mill Creek and found that passage may be impeded, partially or completely, at all flows and success of reaching the lake hinged on individual freshwater entry time. In addition, results from this work indicate that most sockeye in this system are lake spawners.

Mill Creek is a moderate gradient system with a largely bedrock channel substrate that averages 8-10 m in width. It has four waterfalls ranging from 2-10 m in relative elevation change. Moving upstream from saltwater, the structures become less obstructive for fish passage. Mill Creek is also highly subject to dramatic increases in flow velocities and discharge following periodic heavy rainfall common to the area. In general, Mill Creek is characteristic of most moderate sized southeast Alaska streams of similar channel type (large contained "LC"; USFS 1992), but Mill Creek is only 1.2 km long. On average, it took sockeye over four days to migrate from saltwater into Virginia Lake, and this migration included the use of a fishpass structure around the most formidable waterfall. This translates to an average rate of about 0.29 km/d. In a similar study with sockeye salmon from a glacially turbid system, radio-tagged sockeye moved through 30 km of the Kasilof River at a rate of 4.2 km/d (Burger et. al. 1995). Clearly, Virginia Lake sockeye take their time to move such a short distance, but it is unclear as to why this is the case.

A group of recent Canadian research projects evaluated behavior, effectiveness, and physiological responses of sockeye salmon migrating through areas of difficult passage (Hinch et. al. 1996, Hinch and Rand 1998, Rand and Hinch 1998, Hinch and Bratty 2000, Hinch and Rand 2000, Hinch et. al. 2002, Standen et. al. 2002). The research mainly occurred at the Hell's Gate section of the Fraser River in British Columbia, which is a constricted, bedrock channel that creates high velocity flows, especially at spring runoff. A fish passage structure was constructed in 1946 to facilitate salmon migration at one particularly difficult area. The research work used a combination of direct measurement of physiological responses, bioenergetics modeling, and standard and electromyogram radio telemetry to track individual fish movements and physical/physiological responses while they attempted to migrate upstream. Results showed that successful fish (i.e., fish that migrated through difficult areas and continued upstream to spawning grounds) expended less energy by swimming slowly and consistently, and only used burst speed swimming to make quick adjustments or only for short distances. These fish were efficient at finding and using low velocity and reverse flow areas (e.g., shallow areas near the streambank) to swim through. In addition, successful fish had a short residency time in downstream areas before entering the high velocity areas. Unsuccessful fish expended significantly more energy while trying to migrate through more turbulent, higher velocity areas.

These fish quickly burned up valuable energy reserves and eventually died because they likely became disoriented and struggled excessively in the high flow areas. In addition, some unsuccessful fish held in protected downstream areas for significantly prolonged periods before entering difficult areas, which also resulted in passage failures. Interestingly, these efforts also found that sockeye males tended to expend more energy than females in areas of difficult passage.

Virginia Lake sockeye may exhibit similar migration characteristics to the failed fish in the aforementioned studies because the channel containment and structure creates a preponderance of steep, high-velocity flow areas that, even at low or normal discharge levels, cannot be avoided. In other words, Virginia Lake bound sockeye may be pushed to lethal or sub-lethal exhaustion thresholds while negotiating Mill Creek. In addition, a substantial number of adult sockeye were observed holding in the estuary below the downstream waterfall well beyond the peak of the run. Failure to enter Mill Creek probably lowers the exhaustion threshold resulting in more fish that fail to migrate to the lake and spawning grounds.

Another Canadian sockeye study examined migration dynamics, spawning distributions, and tagging stress (radio transmitter) in the Chilko system, British Columbia (Schubert and Scarborough 1996). This study found that Chilko sockeye traveled upstream at an average rate of 12.4, 5.76, and 3.84 km/d, respectively, for three different stages of the run ranging from early to late. Results from observations at Mill Creek exhibit a similar pattern of increasing travel time to move upstream (i.e., a decreasing migration rate) by sockeye entering the system over the course of the run. This effect is especially apparent if entry is after the peak of the run in mid-August. In addition, the Canadian research found a high, but not statistically significant number of ruptured stomachs in tagged sockeye that were examined from recovered carcasses. The researchers also found that radio-tagged females had a diminished spawning success that probably resulted from complications associated with ruptured stomachs. However, they concluded that stomach rupturing was not a direct result of the tagging process, but rupturing resulted from the atrophy and shrinkage of the stomach during the spawning cycle. These researchers observed similar anomalous behavior elicited by some tagged fish in this study in terms of disappearance after lake entry and subsequent lake exit after entry. Though this behavior was not readily explainable, they rationalized the behavior occurred because of negative effects experienced as a result of stomach rupturing over time. Unfortunately, our data to substantiate these findings are incomplete because we were unable to recover and examine any intact, tagged carcasses. Interestingly, Ramstad and Woody (2003) experienced only two mortalities among the 59 tagged fish in their tag retention and mortality study. They found these fish to have ruptured stomachs, but they also found two tagged fish that didn't die during the study to have ruptured stomachs. Their study used only bright pre-spawn fish that were captured at the early part of the run. It is possible that many of the unsuccessful migrations observed in the present study may have resulted from tagging injuries incurred by senescent fish. Fish trapped after early August were darker, which indicated the onset of senescence and atrophy to internal tissues.

The previous examples have extremely important implications to the assumption that the three upstream waterfalls in Mill Creek created at least partial barriers to migration prior to and during the implementation of this study. Mill Creek maintained low or normal flows (relative) during

river mouth may affect the migration dynamics of this run. The relatively high concentration of motorized boats and gill nets at the early part of the run may sufficiently deter fish from approaching the system at a more desirable time. Regardless of the mechanism, a continued unnecessary loss of a significant component of the run would likely have a deleterious effect on the overall sustainability of this fishery.

The results from tracking tagged fish through the spawning period imply that the sockeye salmon in this system are predominantly lake spawners. This is not an uncommon trait for this species (Foerster 1968, Burgner 1991, Burger et. al. 1995, Gustafson et. al. 1997), but it is in contrast to the predominantly stream spawning nature of sockeye in the McDonald Lake system from which the progeny for the Virginia Lake bioenhancement were taken (Halupka et. al. 1995).

Sockeye salmon are highly precise in their ability to home into natal spawning systems and often to the same area where they were spawned and hatched (Hasler and Scholz 1983; Blair and Quinn 1991; Burgner 1991; Varnavskaya et. al. 1994; Ueda et. al. 1998), and imprinting on these locations generally occurs during the embryonic and alevin stages of development (Burgner 1991, Varnavskaya et. al. 1994). With this in mind, two possible explanations come to light regarding the observed spawning patterns at Virginia Lake. First, if the predominance of lake spawning is a regular pattern and if the McDonald stock is truly a stream spawning stock, it is possible that the endemic Virginia Lake stock is inherently lake spawning and recent observations indicate a substantial decline in the enhanced McDonald Lake fish. Second, even if the McDonald Lake stock are truly stream spawning, the fish reared for the Virginia Lake bioenhancement were first incubated and hatched in a remote hatchery facility and then transplanted directly to Virginia Lake as fry. These fish never had a chance to imprint on one of the lake tributaries and are simply returning to the place where their parents spawned – somewhere in Virginia Lake. Of course, hard data are not available to support or refute these conjectures, but a comprehensive DNA/genetics analysis might be warranted to shed light on this problem. As an aside, but certainly related to the aforementioned, the Porterfield and Glacier Creeks do not become saturated with spawning salmon, which would rule-out overcrowding on the spawning grounds and displacement of some individuals to less optimum sites in the lake.

The focus of this study was the upstream migration pattern and spawning distribution of sockeye salmon in Virginia Lake. Results indicated Mill Creek can hinder migration rates and success at most flow levels, and past observations suggest that extreme high flows make Mill Creek impassable to sockeye. In addition, Virginia Lake sockeye appear to be primarily lake spawning, but results are largely inconclusive as to the specific mechanism driving this characteristic. These findings provide some resolution to the declining escapement trend at Virginia Lake. However, there remains a need to better define the juvenile sockeye growth and survival dynamics, which could have a more substantial effect on overall population trends than diminished spawner recruitment and success.

FINAL CONCLUSIONS AND RECOMMENDATIONS

After 15 years of sockeye salmon enhancement work on Virginia Lake, results from monitoring work suggest that management efforts to increase the size and numbers of fish returning to the system were largely unsuccessful. In addition to rational provided in the present study, Cady and Reed (2003) present recent trends and a host of reasons as to why the sockeye run has decreased since the mid-1990's. The following list outlines a recommended course of action for the future management of the system.

1. First and foremost, a realistic management goal for Virginia Lake sockeye salmon must be established before any other intensive management activities are to occur in this system. The "trial-and-error" management used in this system has resulted in a diminished stock and large data-gaps that prevent a sound, cumulative analysis of the population and ecosystem trends. As an example, a minimum and realistic escapement threshold could be established that is desirable for the Virginia Lake system to maintain (e.g. 10,000 spawners), and the question raised, "Can the system reach and maintain this escapement?" Establishing a clear and realistic goal and defining the research and management pathways to determine its feasibility is the only available route to take at this point to prevent any further waste of resources.
2. Data gaps need to be identified and prioritized. Lake limnology is the only relatively complete data set available at this time. Unfortunately, juvenile sockeye data exists for many years but it is limited to a single fry survey each year and estimates are probably unreliable. Only two years of semi-reliable adult escapement data are available. Outside of possibly modifying Mill Creek to better facilitate adult passage (see no. 6 below), emphasis should be placed on obtaining the data to better understand the juvenile dynamics in the system. This could include fry surveys, smolt emigration counts, and smolt condition factor assessments or a combination of these.
3. The subsistence harvest program should be modified to target the less efficient portion of the run. Observations from the last three years of monitoring work suggest the fish entering Mill Creek during and before the first week of August are most successful at migrating to Virginia Lake and completing the spawning cycle. If the current open season were changed from a 31 July closure to closed until 10 August (hypothetical), then the most reproductively successful portion of the run would be protected. However, the question would remain regarding the sustainability of the run if overall returns remained below 3,000 fish (estimated). Recent subsistence permit data suggest that annual harvest at Mill Creek is between 300 and 600 fish. If returns continue to decline, and considering that spawning escapement may actually be a fraction (75-80% during a low or normal flow year) of total escapement, then a continued harvest level of several hundred fish will likely jeopardize the run. Modifying the legal harvest dates will not ensure the longevity of the run, but it will protect the component of the run that would most likely ensure its longevity.

4. Fertilization treatments should cease and desist at least until a better understanding of the whole system dynamics is achieved. It is highly recommended to maintain the limnology surveys for at least three years without fertilization to obtain baseline characters within the phytoplankton and zooplankton communities.
5. A genetics or DNA study is recommended to assess the question of stock heterogeneity within the system. Samples from Virginia Lake could be compared to those of McDonald Lake to determine the degree of relatedness among the stocks. Significant differences between the genetic constitution of the two stocks could explain or partially explain some observed anomalies such as 1) the predominance of lake spawning in Virginia Lake versus stream spawning in McDonald Lake or 2) the migration difficulties observed in Mill Creek because McDonald Lake fish have an easy swim to the lake.
6. The only physical manipulation recommended at this time concerns the modification of the second upstream waterfall at the head of the Flume Pool. Telemetry tracking data indicate prolonged residency in the Flume Pool, which suggests this structure presents at least a partial migration barrier to sockeye salmon. There is also some evidence to suggest that a 150 m section of Mill Creek between the next pool upstream of the Flume Pool and the third upstream waterfall presents a migration obstacle, but practicality of manipulating part or all of this section is infeasible.

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APPENDICES

Appendix A. Summary statistics for the 100 radio-tagged Virginia Lake sockeye salmon in 2003.

Fish No.	Tag Frequency (MHz)	Tag Code	Sex	Length (mm)	Age	Tag Date	Lake Arrival Date	Lake Arrival Time	Travel Time (days)	Fate^a	Spawn Location^b
1	168.105	15	M	550	1.2	22-Jul	26-Jul	22:50	4.50	Sp	NShVL
2	168.130	15	M	580	2.2	22-Jul	29-Jul	9:00	5.92	Sp	NShVL
3	168.155	15	F	540	1.3	22-Jul	26-Jul	22:30	4.46	Sp	NShVL
4	168.180	15	F	520	1.2	27-Jul	29-Jul	23:40	1.50	Sp	NShVL
5	168.206	15	F	520	2.2	27-Jul	01-Aug	22:30	5.46	Sp	NShVL
6	168.221	15	M	580	1.3	27-Jul	01-Aug	22:10	6.42	Sp	NShVL
7	168.246	15	M	610	1.3	27-Jul	29-Jul	23:20	1.46	PSp	?
8	168.271	15	M	605	2.2	27-Jul	28-Jul	22:50	0.48	Sp	NShVL
9	168.296	15	F	550	1.3	27-Jul	29-Jul	0:20	0.48	Sp	NShVL
10	168.320	15	M	545	2.2	27-Jul	01-Aug	22:55	5.42	PSp	?
11	168.105	16	F	540	2.2	29-Jul	05-Aug	22:55	7.58	Sp	NShVL
12	168.130	16	M	480	2.2	29-Jul	01-Aug	2:35	3.54	Sp	SPtr
13	168.155	16	M	590	1.2	29-Jul	01-Aug	4:17	2.77	Sp	NShVL
14	168.180	16	M	590	1.3	29-Jul				F ₁	
15	168.206	16	M	535	1.3	29-Jul	02-Aug	23:10	4.54	Sp	Glc
16	168.221	16	F	540	2.2	29-Jul	03-Aug	10:30	5.02	Sp	NShVL
17	168.246	16	M	610	2.3	30-Jul	02-Aug	23:00	3.44	Sp	NShVL
18	168.271	16	F	570	1.3	30-Jul	30-Jul	22:25	1.40	Sp	NShVL
19	168.296	16	F	545	1.2	30-Jul	02-Aug	0:20	2.46	Sp	NShVL
20	168.320	16	F	535	1.3	30-Jul	02-Aug	3:00	3.42	Sp	NShVL
21	168.105	17	F	540	2.2	31-Jul	04-Aug	22:30	4.50	Sp	NShVL
22	168.130	17	M	525		31-Jul				F ₁	
23	168.155	17	M	625	1.3	31-Jul	04-Aug	22:30	4.50	Sp	Glc

Fish No.	Tag Frequency (MHz)	Tag Code	Sex	Length (mm)	Age	Tag Date	Lake Arrival Date	Lake Arrival Time	Travel Time (days)	Fate^a	Spawn Location^b
24	168.180	17	F	490	1.2	31-Jul	04-Aug	0:10	3.54	Sp	NShVL
25	168.206	17	F	570	2.2	31-Jul	02-Aug	23:15	2.50	Sp	NShVL
26	168.221	17	M	600	2.3	01-Aug	08-Aug	22:35	7.46	Sp	PtrCnt
27	168.246	17	F	560	1.3	01-Aug	08-Aug	2:49	6.65	Sp	Glc
28	168.271	17	F	620	1.3	01-Aug	04-Aug	15:55	3.19	Sp	
29	168.296	17	M	610	2.3	01-Aug	06-Aug	0:30	4.52	Sp	
30	168.320	17	M	620	2.3	01-Aug	09-Aug	22:45	9.46	Sp	NShVL
31	168.105	18	F	560	2.2	02-Aug	05-Aug	4:55	2.77	Sp	NShVL
32	168.130	18	F	540	1.2	02-Aug	05-Aug	0:30	2.94	Sp	NShVL
33	168.155	18	M	565	2.2	02-Aug	13-Aug	3:15	10.67	Sp	NShVL
34	168.180	18	M	530	2.2	02-Aug	06-Aug	1:05	3.63	Sp	Glc
35	168.206	18	F	535	2.2	02-Aug	20-Aug	12:52		F ₁	
36	168.221	18	M	570	1.2	03-Aug	06-Aug	23:10	3.50	Sp	NShVL
37	168.246	18	M	540	1.2	03-Aug	06-Aug	3:20	2.69	Sp	NShVL
38	168.271	18	F	500	1.2	03-Aug	06-Aug	3:55	2.69	Sp	NShVL
39	168.296	18	F	525		03-Aug	07-Aug	22:15	4.44	Sp	NShVL
40	168.320	18	F	570	1.3	03-Aug	08-Aug	18:05	5.27	Sp	NPtr
41	168.105	19	F	520	1.2	04-Aug	07-Aug	2:05	2.71	Sp	NShVL
42	168.130	19	M	560	2.2	04-Aug	05-Aug	21:55	1.52	Sp	NShVL
43	168.155	19	M	510		04-Aug	08-Aug	3:45	3.77	Sp	NShVL
44	168.180	19	F	595	1.3	04-Aug	08-Aug	23:55	4.58	Sp	SPtr
45	168.206	19	M	635	2.3	04-Aug	06-Aug	2:35	1.71	Sp	?
46	168.221	19	M	560	2.2	05-Aug	08-Aug	18:05	3.23	Sp	?
47	168.246	19	F	585	2.3	05-Aug	09-Aug	3:35	3.63	Sp	NPtr
48	168.271	19	F	510	1.2	06-Aug	08-Aug	22:30	2.44	Sp	NShVL
49	168.296	19	M	600	2.3	06-Aug	10-Aug	23:30	4.56	Sp	?
50	168.320	19	F	580	1.3	06-Aug	10-Aug	23:45	4.58	Sp	NShVL
51	168.105	20	F	510	1.2	07-Aug	09-Aug	22:25	2.60	Sp	NShVL
52	168.130	20	F	560	2.2	07-Aug	10-Aug	22:50	3.58	Sp	NShVL
53	168.155	20	M	555	1.3	07-Aug	12-Aug	2:25	5.58	Sp	?

Fish No.	Tag Frequency (MHz)	Tag Code	Sex	Length (mm)	Age	Tag Date	Lake Arrival Date	Lake Arrival Time	Travel Time (days)	Fate ^a	Spawn Location ^b
54	168.180	20	M	580	1.3	07-Aug				F ₂	
55	168.206	20	M	575	2.3	07-Aug	10-Aug	22:50	3.54	Sp	?
56	168.221	20	M	550	1.2	08-Aug	13-Aug	22:20	5.52	Sp	?
57	168.246	20	M	570	1.3	08-Aug	09-Aug	22:36	1.52	Sp	NShVL
58	168.271	20	F	540	2.2	08-Aug	12-Aug	22:40	2.54	Sp	NShVL
59	168.296	20	F	505	1.1	08-Aug	11-Aug	3:50	0.73	Sp	NShVL
60	168.320	20	F	555		08-Aug	15-Aug	22:20	5.50	Sp	?
61	168.105	21	M	625	2.3	09-Aug				F ₂	
62	168.130	21	F	540		09-Aug	11-Aug	1:50	1.65	Sp	?
63	168.155	21	F	580	1.3	11-Aug	13-Aug	22:20	2.52	F ₃	
64	168.180	21	M	640	2.3	11-Aug				F ₁	
65	168.206	21	F	540	2.2	11-Aug				F ₂	
66	168.221	21	F	595	1.3	12-Aug	14-Aug	4:35	1.79	Sp	?
67	168.246	21	M	520		12-Aug	19-Aug	22:10	7.52	Sp	?
68	168.271	21	F	550	2.3	13-Aug	15-Aug	2:40	1.65	Sp	NShVL
69	168.296	21	F	525	2.2	13-Aug				F ₁	
70	168.320	21	M	520	1.2	13-Aug	17-Aug	4:25	4.06	Sp	?
71	168.105	22	F	560	2.2	14-Aug				F ₁	
72	168.130	22	M	550	2.2	14-Aug				F ₁	
73	168.155	22	F	510	1.2	15-Aug	20-Aug	15:50	5.21	Sp	?
74	168.180	22	M	560	2.2	15-Aug	18-Aug	22:10	1.46	F ₃	
75	168.206	22	M	560		15-Aug	17-Aug	1:20	1.60	F ₃	
76	168.221	22	F	510	2.2	18-Aug				F ₁	
77	168.246	22	M	540	2.2	18-Aug	26-Aug	2:05	7.56	F ₃	
78	168.271	22	M	600	1.3	18-Aug	22-Aug	16:00	4.15	F ₃	
79	168.296	22	F	570	2.3	18-Aug	25-Aug	3:25	6.63	F ₃	
80	168.320	22	M	530	1.2	18-Aug	22-Aug	21:30	4.35	F ₃	
81	168.105	23	M	590	2.2	19-Aug				F ₁	
82	168.130	23	F	555	1.3	19-Aug	22-Aug	13:37	3.10	F ₃	
83	168.155	23	F	525	2.2	23-Aug				F ₁	

Fish No.	Tag Frequency (MHz)	Tag Code	Sex	Length (mm)	Age	Tag Date	Lake Arrival Date	Lake Arrival Time	Travel Time (days)	Fate^a	Spawn Location^b
84	168.180	23	F	590	1.3	23-Aug				F ₁	
85	168.206	23	M	590	2.2	23-Aug				F ₂	
86	168.221	23	M	575	2.2	25-Aug	28-Aug	23:58	3.56	F ₃	
87	168.246	23	M	610	1.3	25-Aug	30-Aug	19:57	5.40	Sp	NShVL
88	168.271	23	M	525	1.2	25-Aug	04-Sep	0:44	9.56	F ₃	
89	168.296	23	F	540		25-Aug	30-Aug	21:05	5.42	Sp	?
90	168.320	23	F	620	2.3	25-Aug				F ₁	
91	168.105	24	F	520	2.2	26-Aug	01-Sep	13:20	6.17	Sp	?
92	168.130	24	F	530	2.3	26-Aug				F ₁	
93	168.155	24	M	600	2.3	26-Aug	03-Sep	23:23	8.58	F ₃	
94	168.180	24	M	580	2.2	26-Aug	04-Sep	3:49	8.58	Sp	?
95	168.206	24	F	570	2.3	26-Aug				F ₁	
96	168.221	24	M	530	1.2	28-Aug				F ₁	
97	168.246	24	M	640	2.3	28-Aug	31-Aug	12:28	3.15	F ₃	
98	168.271	24	F	570	1.3	28-Aug				F ₁	
99	168.296	24	F	530	2.2	29-Aug				F ₁	
100	168.320	24	M	550	2.2	05-Sep				F ₁	

^a See Table 1 for definition of fates.

^b Spawning locations: “NPtr” = North Porterfield Creek, “SPtr” = South Porterfield Creek, “PtrCnt” = Porterfield Connector Arm, “Glc” = Glacier Creek, “NShVL” = north shore of Virginia Lake, “?” = unknown but probable lake spawner

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